Three-Dimensional Rendering and Image Analysis of Coronal Loops

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Since launch in 1991, the Japanese solar satellite Yohkoh has been revealing many new aspects of solar coronal physics: coronal structures and dynamics, gigantic arcades formations, cusp-shaped flares, soft x-ray jets, microflares, single-loop flares, and loop-loop interactions. MSFC was the management center for the Soft X-Ray Telescope (SXT) built by Lockheed for the ISAS (Institute of Space and Aeronautical Sciences) in Japan. MSFC involvement in solar x rays and magnetic fields has been extensive: Apollo Telescope Mount's Solar X-Ray Telescope S–056, MSFC Solar Vector Magnetograph, MSFC and Stanford x-ray telescope rocket programs, High Energy X-Ray Telescope, Soft X-Ray Instrument, and Solar-B. This research is extending this effort.

The objective of this research is to expand MSFC's in-house capabilities by developing innovative three-dimensional dynamic displays, tools, and programs to simulate gaseous configurations, interactions, and dynamics through the rendering of three-dimensional gaseous volumes into two-dimensional images. Having these line-of-sight images allows the backward interpretation of observations to obtain the three-dimensional structure of the solar phenomena. The main intention of the research is to develop pseudo-imaging techniques of soft x-ray emission to compare with observations in order to investigate the structure of the coronal magnetic field by analyzing the field line and emission characteristics. Data analysis techniques will be applied to the MSFC and Themis/France vector magnetograms and the Kitt Peak National Observatory longitudinal magnetograms to characterize the spatial and temporal changes of magnetic and electric current systems within active regions.

In the Solar Physics Branch at Marshall, research is conducted on solar magnetic fields and their physical associations and effects in the photosphere, corona, and interplanetary medium. Extensive efforts have been carried out in relating the MSFC vector magnetograms to flare theories. This research continues this extremely useful research by describing the observed coronal magnetic structures in the solar atmosphere in relation to the observed photospheric magnetic field on the solar surface. The photospheric field is derived from magnetograms. Using this data and observed x-ray images of the Sun, we are developing general data analysis tools to be used to produce the soft x-ray images by reconstruction and using these images to compare with data (fig. 171). The research objective is directed at the overall goal of being able to define the available free-energy via the three-dimensional magnetic and electric current morphology transversing through the solar atmosphere. The research, in part, is the development of software that will display pseudo soft x-ray images given magnetic field lines, density, and temperature. The development process is as independent of specific models as possible to allow for many models in the final version. The crucial development here is to provide an efficient computer algorithm that renders a three-dimensional volume into a two-dimensional image with adequate quality compatible for analysis and comparison with observations (e.g., from soft x-ray telescope (SXT)/Yohkoh). The code will provide a systematic comparison between (1) observed coronal flux tubes and models, and comparison between (2) coronal flux tubes and their photospheric footpoints. Using existing codes and scaling laws to determine the coronal density and temperatures, and an instrument response code, one can determine theoretically the observed emission characteristics for each volume cell (voxel). This analysis package is the major component of the research. With this software, the

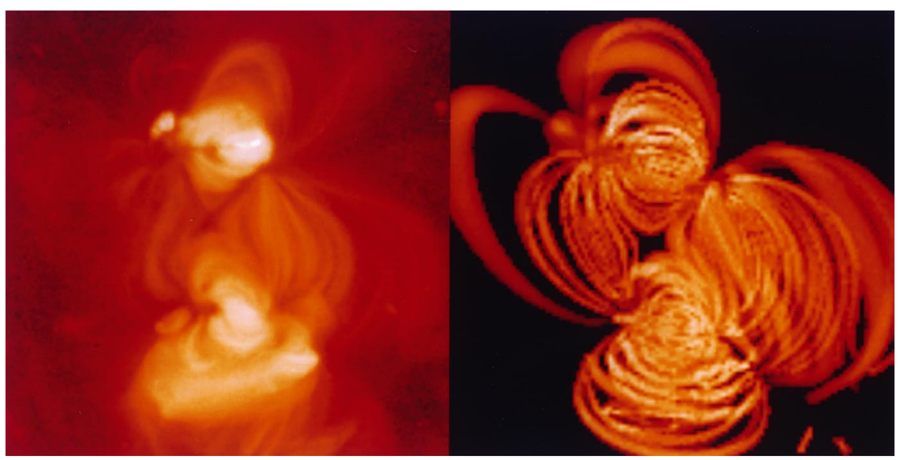

FIGURE 171.—A comparison of a soft x-ray image from the Japanese/American solar instrument SXT/Yohkoh (left) with a set synthesized coronal loops (right) is shown. The synthesized image was produced under the CDDF project. Initial comparison of the results are promising in that the overall morphology of the images are similar. As more detail modelling is included the important physical parameters of the coronal plasma will be established. The views shown here are a low resolution version of the original digital display.

backward interpretation can begin; that is having a two-dimensional image, the three-dimensional configuration can be inferred and further studies of coronal temperatures, emission characteristics, field modeling, footpoint and photospheric correspondence will proceed.

The description of the coronal magnetic field is a key component in understanding solar activity. Hence, this topics is in direct support of flight- and ground-based vector magnetograph programs which are specific NASA programs and a focus of the activities of the MSFC Solar Science Branch. The results are of particular importance to the mechanisms of solar variability (MSV) and space-borne magnetograph programs which are aimed at understanding the physical cause of variations in and from the Sun. The free magnetic energy which drives much of the variation is directly connected to the magnitude of the electric currents and heating in the solar atmosphere. To understand the dynamics of the x-ray imagery (e.g., from Yohkoh) one needs again to understand the electric currents (the source of energy) and the coronal configuration. The general analysis of the magnetic structures and their associate electric current systems will discriminate between contending theoretical models. There is clearly a need for this analysis and relates to observations from the MSFC vector magnetograph and the development of the next generation solar orbiting instruments.

The research program is developing a formal basis for deriving and investigating solar magnetic structures and to obtain a better physical understanding of these results. MSFC magnetograms will be analyzed extensively to characterize the photospheric magnetic fields. The specific strength of this research is that the scientific investigation continues a strong program by the Solar Physics Branch in the area of magnetic field analysis. These studies are of the highest scientific merit to solar physics and are fundamentally important to the NASA Space Physics Program (e.g., Solar-B, Solar Probe, Solar Stereo Missions). The objectives are assured through a thorough technical approach. The relevance of the work to NASA's space physics program lies in the deeper understanding it will provide of the processes underlying the observed structure of solar active regions, which are the main contributors to solar variability in ultraviolet and x rays.

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Educational Involvement: The MSFC Student Volunteer Service Program (SVSP) has provided useful research experiments to local high school students.

Biographical Sketch: G. Allen Gary received his Ph.D. in physics in 1969 from the University of Georgia. He is in the Solar Physics Branch at Marshall Center, investigating the nature of coronal structures and solar magnetic fields. His research also includes the general study of the magnetic field's configuration, evolution, and morphology together with estimation of the energy content of active regions. His theoretical work involves developing models of linear and nonlinear force-free magnetic fields and electric currents in the solar chromosphere-corona.